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Standoff Range Improvement of Electro-Optical Television Guidance Systems

by

Marc L. Moulton

Weapons Department

JANUARY 1980

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FOREWORD

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This report is released at the working level. It is possible that additional development and testing will be done in the future which will allow extension and refinement of the results.

This report was reviewed for technical accuracy by W. H. Woodworth.

Approved by
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Weapons Department
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(U) *Standoff Range Improvement of Electro-Optical Television Guidance Systems*, by Marc L. Moulton. China Lake, Calif., Naval Weapons Center, January 1980. 16 pp. (NWC TP 6161, publication UNCLASSIFIED.)

(U) A technique for increasing the maximum range at which a target can be identified and acquired (standoff range) by a television electro-optical guidance system when used under hazy atmospheric conditions has been developed and flight-tested. The standoff range increase is obtained by extending and limiting the spectral response of the television camera to near infrared and incorporating electronic contrast enhancement to increase the target contrast. This method provides increased standoff range by factors from 2 to 4.

CONTENTS

INTRODUCTION

An electro-optical, visible spectrum television guidance section has been modified to increase video contrast and consequently extend standoff range (the maximum range at which a target can be identified and acquired) when used in hazy atmospheric conditions. An available Condor guidance section was used. This guidance section uses an antimony trisulfide target vidicon, as do most of the current visible spectrum systems, and its camera performance is fairly typical of systems of this kind.

Modification primarily consisted of replacing the existing vidicon with a silicon target vidicon to obtain increased response in the near infrared (IR), and replacing the existing video amplifier with one incorporating electronic contrast enhancement. Also, the Condor optics were replaced with a continuous zoom lens for improved initial target acquisition and discrimination.

The modified Condor and a standard Walleye guidance section were flight-tested to obtain a comparative evaluation of performance under realistic conditions.

FORWARD/OBJECTIVE

The video quality of visible spectrum electro-optical guidance systems, especially those utilizing antimony trisulfide vidicons, is degraded by hazy atmospheric conditions to such an extent that contrast and standoff range are considerably reduced by even very light haze. The objective of this project is to show that with practical modifications to a conventional electro-optical system, it is possible to obtain a substantial improvement in performance in a hazy atmosphere.

PERFORMANCE OF VISUAL AND NEAR IR SYSTEMS

Atmospheric haze causes both scattering and absorption of radiation through it with the effect that the contrast of an object viewed through the haze is reduced.

Also, radiation from the source of illumination (the sun) is reflected by the haze toward the detector. This backscattering increases the average illumination of the detector, thus further reducing the contrast ratio at the detector. The scattering effect is a function of wavelength and particle size. Atmospheric transmittance, T_a, over a path length R may be expressed by

$$T_a = e^{(-\sigma R)} \tag{1}$$

where σ is the spectral attenuation coefficient or "extinction coefficient" (RCA Corporation handbook [1]) and is a complex function of wavelength and particle size. In general, over the visible and near IR spectrum, σ varies inversely with wavelength. The scattering effect is greater at the shorter wavelength, or blue end of the visible spectrum, but scene contrast in a black and white vidicon system is generally not heavily dependent on the blue spectral content. Therefore, optical filtering to restrict the illumination of the vidicon to the red end of the spectrum is generally employed to increase the contrast under hazy conditions. Since the spectral sensitivity of an antimony trisulfide vidicon peaks at about 550 nanometers (nm) and falls to 25% at about 750 nm, filters that cut off at wavelengths longer than about 600 nm cannot be used without objectionable loss of sensitivity. However, the response of a silicon target vidicon peaks at about 700 nm and has a useful output to about 1000 nm. It also has much greater sensitivity than antimony trisulfide. This allows the use of near IR filters with cutoff wavelengths as long as 900 nm to provide contrast improvement over that possible with an antimony trisulfide vidicon.

ELECTRONIC CONTRAST ENHANCEMENT

Since imaging detectors such as vidicons have limited dynamic range, the sensitivity of a vidicon system must be varied in inverse proportion to the average scene illumination to maintain linear operation. The resulting electrical signal consists of video information varying about a pedestal, and this pedestal is maintained by the sensitivity control at 50% of the peak output. Brightness of the displayed video is proportional to the average value of the video and consequently proportional to the electrical video pedestal. Any attempt to raise the system gain to obtain an increase in displayed contrast then results in a corresponding increase in average brightness of the display. Since contrast is defined as

[1] RCA Corporation. *Electro-Optics Handbook TSEOH-11*, by RCA Corporation, Lancaster, PA, 1974.

$$C = \frac{L_O - L_B}{L_B} \qquad (2)$$

where L_O = luminance of the object and L_B = luminance of the background, an increase of the system gain alone does not result in any increase in displayed contrast. It is possible, however, with suitable electronic circuitry to remove the electrical brightness pedestal. After the pedestal is removed, system gain can be increased and will result in an increase in amplitude of only the useful video information. A fixed pedestal can then be reinserted to restore the output to a normal video waveform. This will increase the contrast of the output or displayed video by an amount proportional to the increase in gain.

There are two primary limitations to this form of contrast enhancement, one of which is the system noise. As the contrast ratio at the detector falls, the electrical signal-to-noise ratio also falls. If the gain is raised too far, the video output will become excessively noisy and eventually, a point is arrived at where further increase in output contrast ratio does not improve target detection or recognition. This limit was reached in the Condor camera when the electronic gain was increased by about 10 to 1. Since most of the electrical noise is generated in the video preamplifier, improving the preamplifier noise characteristics would allow a corresponding increase in contrast enhancement gain.

A second limitation to the amount of useful contrast enhancement is flatness of the video field. Simple pedestal removal techniques subtract a uniform pedestal from the video signal, and any background nonuniformity caused by the vidicon or optics (such as shading, portholing, etc.) remains and is amplified by the contrast enhancement circuit, along with the desired video information. When the contrast of this background signal becomes objectionable in the displayed video, no further increase in gain is useful. Silicon target vidicons offer a much flatter field than do antimony trisulfide types, allowing greater contrast enhancement gain to be used.

COMPARISON OF CONTRAST-ENHANCED VERSUS STANDARD SYSTEMS

The optical contrast of an object, C_R, at range R as a function of scattering along the transmission path may be expressed by

$$C_R = C_o\, e^{(-\sigma_v R)} = \frac{L_{OR} - L_{BR}}{L_{BR}} \qquad (3)$$

where C_O = the inherent contrast at zero range = $\frac{L_O - L_B}{LB}$, σ_V = the average value of the extinction coefficient over the visible range, and L_{OR} and L_{BR} = the luminance of the object and background, respectively, at range R.

The general configuration of a contrast-enhanced television camera system is shown in Figure 1. (An unenhanced system is identical when G_o and G_e = 1.) In Figure 1, G_o is the optical contrast gain, L_{in} is the faceplate illumination of the vidicom, G_e is the electrical contrast gain, and K_1 and K_2 are conversion constants. Gamma, γ, is the exponent of the power function that defines the conversion of input illumination to electrical information by a vidicon (γ_V), or electrical information to illumination by a cathode ray display tube (γ_D). For the transfer function of a system to be linear, the overall gamma should be unity. Electrical gamma correction employed to accomplish this is of the form $e_o = e_{in}^{\gamma_c}$. For a system gamma of one, γ_c, = $1/\gamma_V\gamma_D$. Most conventional systems use a display with a gamma approximately equal to 2 and require a γ_c of $0.5/\gamma_V$. The average gamma of a typical antimony trisulfide vidicon is 0.5 and no gamma correction is required when used with a display where γ_D = 2. The average gamma of a silicon target tube is approximately 1 requiring a γ_c = 0.5.

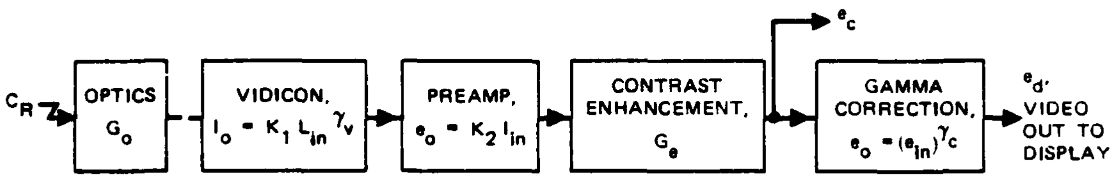


FIGURE 1. Contrast Enhanced Video System.

It is useful to define an electrical equivalent to C_R since electrical parameters are more readily measured in an operating system. However, an equation relating the electrical video output, e_d, to C_R becomes complicated since the nonunity gamma of the system requires each level of illumination to be dealt with separately rather than in the form of a contrast ratio. It is much more convenient to define a relationship for C_R with respect to a point in the system where gamma = 1. This has the advantage that the same relationship is directly proportional to the displayed contrast ratio since the system gamma is also unity at this point.

For the system of Figure 1 with a silicon target vidicon, the gamma is unity at all points from C_R to e_c allowing contrast gain coefficients to be applied directly to contrast ratios. If it is necessary to further relate the actual electrical video output e_d to e_c, this may be done by correcting for gamma on a case by case basis. C_R is then related to e_c as follows.

If the electrical contrast ratio C_e at e_c is defined as

$$\frac{e_o - e_b}{e_b}$$

where e_o is the electrical amplitude of the object and e_b that of the background.

Then

$$C_e = C_R \, G_o \, G_e$$

An overall contrast enhancement gain coefficient may then be defined as

$$G_c = G_o G_e$$

Thus

$$C_e = G_c C_R \tag{4}$$

It is difficult to predict the actual contrast ratio available at the camera since both C_o and σ_v would have to be known. It is possible however to establish the ratio of the ranges at which the contrast, C_e, with enhancement is equal to the contrast without enhancement for a given C_o and G_c. C_e is proportional to displayed contrast so this is also the range ratio that will result in equal displayed contrast of the enhanced versus unenhanced video. If R_2 is the range at which contrast enhancement gain G_c is applied and R_1 the range where $G_c = 1$, then

$$C_{R_1} = C_o e^{(-\sigma R_1)} \text{ and } C_{R_2} = C_o e^{(-\sigma R_2)} \text{ (from Equation 3)}$$

and

$$C_{R_1} = C_{e_1} \text{ and } C_{R_2} = \frac{C_{e_2}}{G_c} \text{ (from Equation 4)}$$

Therefore,

$$e^{\sigma R_1} = C_o/C_{e_1} \text{ and } e^{\sigma R_2} = \frac{G_c C_o}{C_{e_2}}$$

or

$$\sigma R_1 = \ell n\,(C_o/C_{e_1}) \text{ and } \sigma R_2 = \ell n\,(G_c C_o/C_{e_2})$$

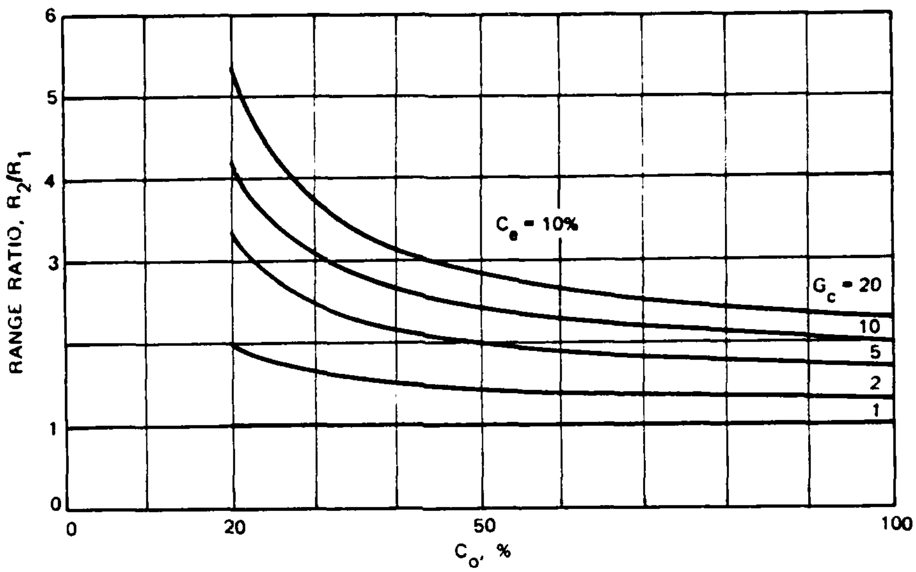
It is desired to establish the ratio of R_2 to R_1 where $C_{e_2} = C_{e_1}$ so

$$C_{e_2} = C_{e_1} = C_e$$

$$\frac{R_2}{R_1} = \frac{\ell n(G_c C_o/C_e)}{\ell n(C_o/C_e)} = \frac{\ell n\,G_c + n(C_o/C_e)}{\ell n(C_o/C_e)} = \frac{\ell n G_c}{\ell n(C_o/C_e)} + 1 \quad (5)$$

A set of curves of Equation 5 is given in Figure 2 that relates R_2/R_1 to C_o for various practical values of G_c. Values for C_e of 10 and 20% were used as reasonable limiting values for reliable target recognition.

Since the range ratio, R_2/R_1, is independent of atmospheric transmission it may be applied as a direct indication of the increase in standoff range provided by the contrast enhancement system. It is apparent from Figure 2 that with reasonable contrast enhancement gain, the standoff range can be increased by at least a factor of 2 over the full range of target contrast. Actual values for R_1 and R_2 can be calculated from Equations 3 and 5 if σ_v and C_o are known. For example, if the path between the target and the detector is obscured by "medium haze" corresponding to a meterological visibility range ($C_R/C_o = 0.02$) of 5 km (16,000 ft), σ_v for a red filtered vidicon is approximately equal to 0.7. [1] For a zero range target contrast of 50% and a displayed contrast of 10%, $R_1 = \ell n(0.5/0.1)/0.7 =$ 2.30 km (7546 ft). If the maximum contrast enhancement gain is 10, $R_2/R_1 = \ell n\,10/\ell n(0.5/0.1) + 1 = 2.43$ and $R_2 = 5.59$ km (18,337 ft).



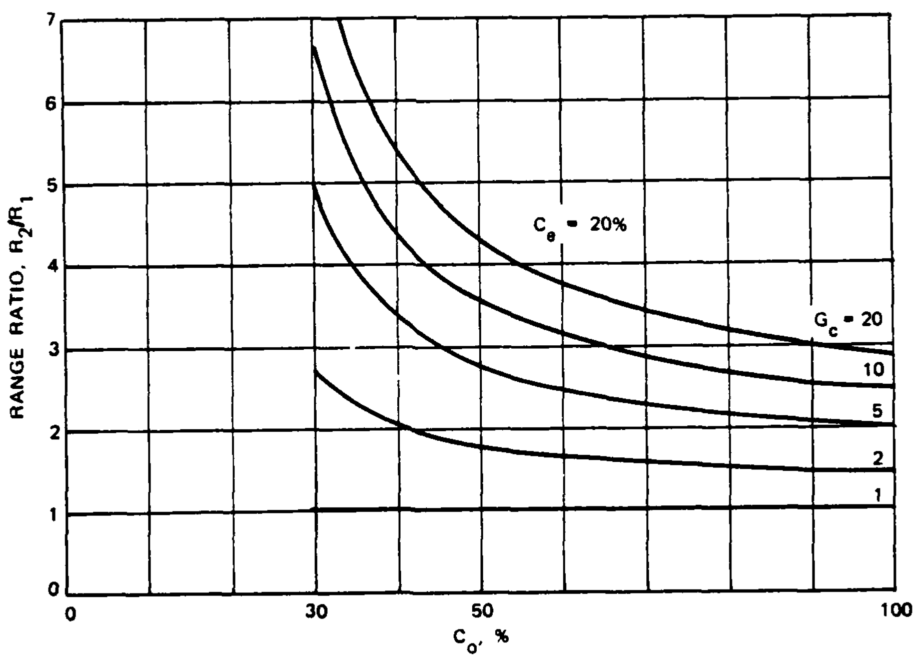


FIGURE 2. Range Ratio, R_2/R_1 for Various Values of C_o, C_e, and G_c.

SYSTEM DESCRIPTION

An available Condor guidance section was modified to incorporate both a silicon target vidicon and electronic contrast enhancement. In addition the original Condor lens was replaced with a zoom lens to evaluate the use of a continuously variable field of view (FOV) for initial target acquisition.

The camera, electronic tracker, and gimbaled platform of the Condor guidance section were adapted from an improved Walleye design.

The major modification required to replace an antimony trisulfide vidicon with a silicon target type is to provide proper light level control. The antimony trisulfide vidicons can be controlled by varying the target voltage whereas the silicon types must be controlled optically.

An RCA C23219 silicon target vidicon assembly with integral yoke and focus coil was used since it is electrically and physically similar to the original Condor vidicon assembly.

A Zoomar F/2, 17- to 70-mm motorized zoom lens and 2X extender were used to provide a physically compact f/4, 34- to 140-mm optical zoom. The zoom lens was linearly coupled to the vidicon deflection circuits by means of a position feedback potentiometer mounted on the lens. The deflection amplitude was configured to vary by 2 to 1 over the 4 to 1 optical zoom range to provide an overall continuous 8 to 1 zoom. The narrowest FOV is approximately equal to a standard Walleye. The motorized zoom lens also included a motorized iris which was used to control the illumination of the vidicon. Control of the iris motor was derived from the signal previously used to control the vidicon target voltage.

A Kodak No. 87 Wratten filter was installed over the front of the lens to limit the response to the near infrared. This filter has the following transmission characteristics: 95% at 820 nm, 50% at 780 nm, 10% at 760 nm, and 1% at 740 nm.

The original Condor video amplifier was replaced with one incorporating electronic contrast enhancement. A block diagram of the camera system is given in Figure 3 and a more detailed block diagram of the video amplifier in

Figure 4. Video from the preamplifier is amplified and DC restored by a keyed clamp. Residual signals in the blanking interval are removed by a keyed clipper. The video is then buffered and used in three places: it is sent to the electronic tracker for derivation of tracking error signals, it is filtered and peak-detected to provide a voltage proportional to vidicon illumination for use by the iris motor control circuit, and it is also sent to an aperture corrector to improve the high-frequency response and then on the contrast enhancement circuit.

The first section of the contrast enhancement circuit removes the video brightness pedestal. This is done by integrating the video to derive a voltage equal to its average value, gating this voltage to remove it during the blanking interval, and subtracting the gated voltage from the video. The resulting video waveform then varies around a new average value of 0 volt rather than a DC pedestal proportional to average scene illumination.

The next section of the contrast enhancement circuit acts to provide a controlled peak output. After removal of the pedestal a signal is derived that is proportional to the peak-to-peak amplitude of the remaining video. This signal is used to control the gain of an amplifier to maintain a constant peak-to-peak output.

A fixed pedestal is then added to the video to restore it to a normal video waveform followed by a black clipper which removes any remaining signal peaks that would exceed the blanking level. The video is then filtered by a 4-MHz, 3-pole linear phase filter to limit the high-frequency video and noise content. Finally, gamma correction is applied, synchronization added, and the composite video signal buffered.

The electronic contrast enhancement system configured as described provided an increase in electrical contrast ratio, C_e, of the output video by a maximum of 7 to 1. Nonuniformity of the video field limited the system at this point. This was primarily due to horizontal deflection nonlinearity. Some electronic correction could have been employed to further flatten the field and allow higher gains to be used. However, it was found that preamplifier noise became objectionable if the contrast ratio was increased much above 10 to 1 so no further attempt to increase the maximum gain was made in this system.

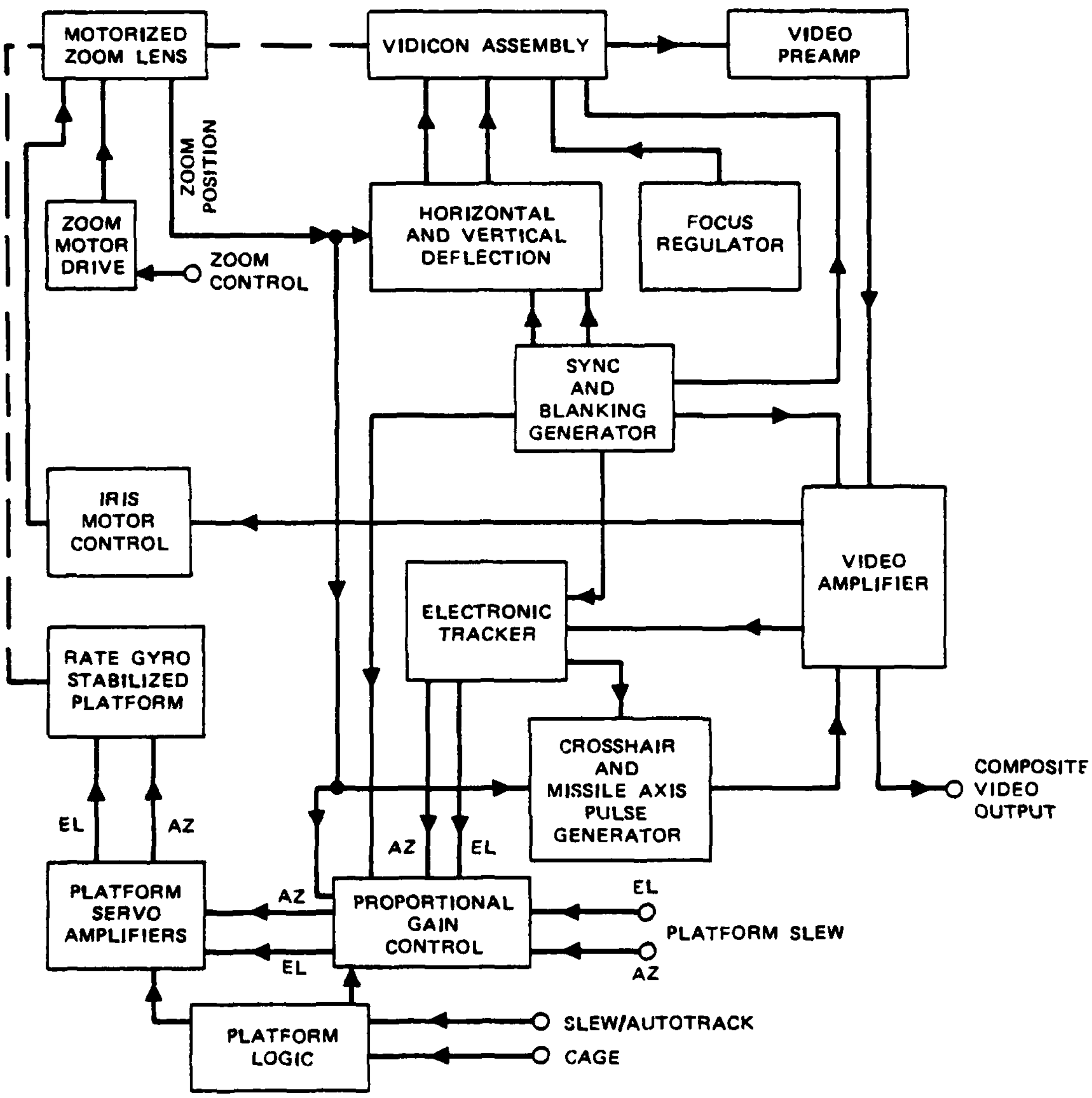


FIGURE 3. Modified Condor Camera System.

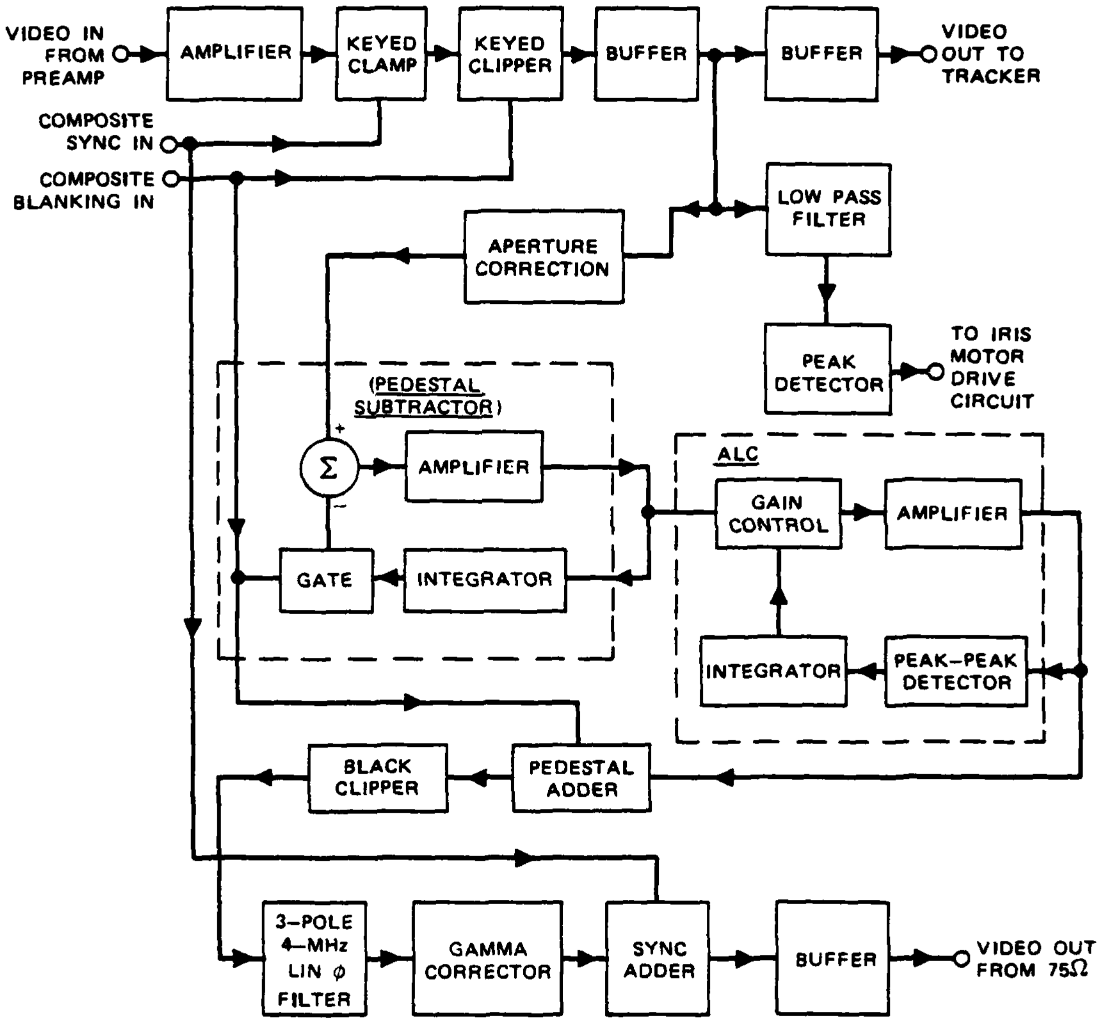


FIGURE 4. Video Amplifier with Contrast Enhancement.

FLIGHT TEST RESULTS

The modified Condor guidance section and a standard Walleye guidance section were loaded on the same aircraft for flight testing and the system was configured to allow rapid switching between the Walleye and Condor video for A-B comparison. A video tape recorder was included and the selected video recorded. A total of five flights were made—three against land targets and two against waterborne targets.

Flight scheduling problems prevented selecting for the desired meterological haze conditions so only one of the flights, over land, was made under conditions of substantial atmospheric haze. The remaining flights were made with visibility varying from light haze to relatively clear conditions. Even so, there was a significant difference in target contrast in nearly all cases and very often a target could be acquired and identified from the video displayed by the contrast-enhanced guidance section before it was visible in either the displayed Walleye video or directly by the operator.

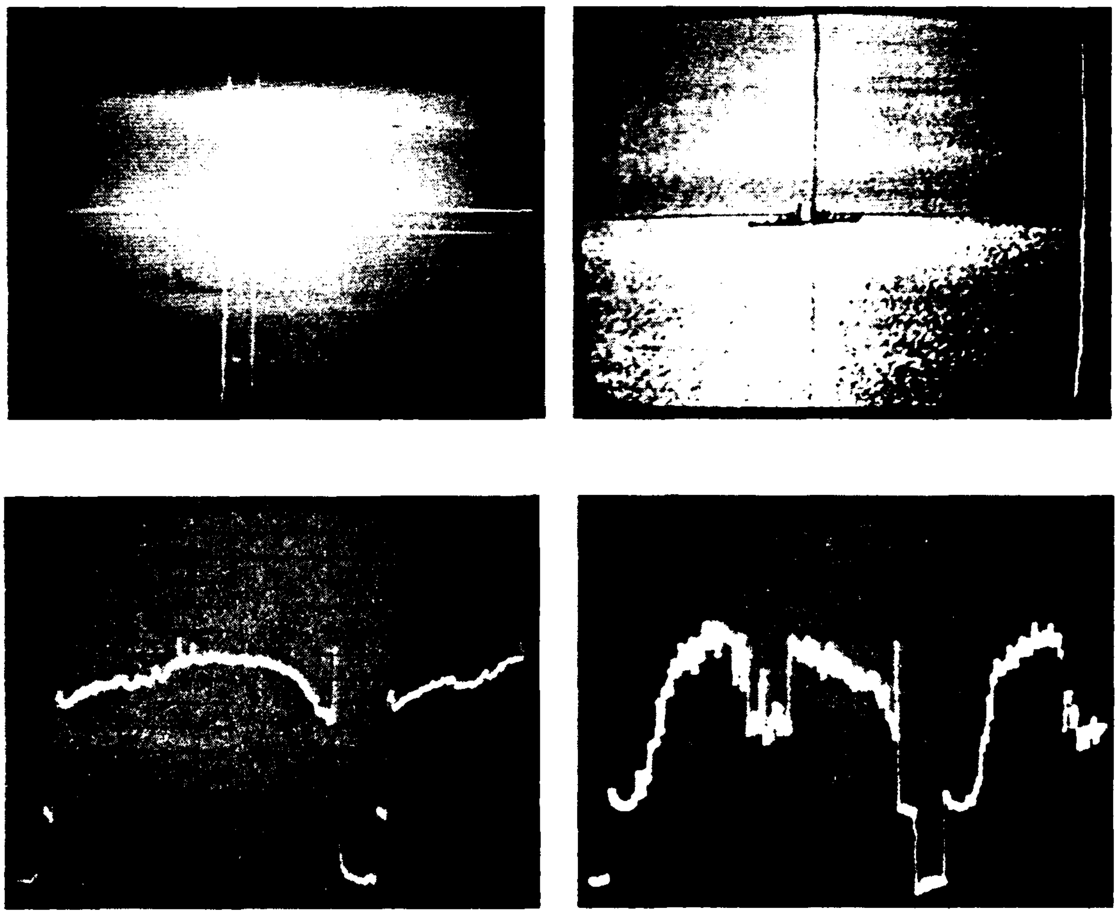
The improvement provided by the contrast enhancement is quite apparent in the samples shown in Figures 5 and 6. Figures 5 and 6 are photographs of the displayed video taken from the video tape recorded during two of the flights and are typical of the contrast improvement that can be obtained. The horizontal FOV of the two cameras is approximately equal. In each case a photograph of the respective waveform of one horizontal line of video through the target is included. These waveforms are at the point in Figure 1 called e_d, where gamma equals 0.5.

Limitations of the flight-test program did not allow measured values to be obtained for meterological conditions, camera-to-target range, or inherent target contrast, so an exact numerical comparison of the standoff range improvement to the predicted values cannot be made. It is possible, however, to make a limited comparison from the available data. For the ship target of Figure 5, the camera-to-target range as estimated from the approximate target size and the camera FOV is about 9 km. The meterological visibility range was estimated to be about 30 km which would correspond to $\sigma_V = 0.13$.[1] Since the video waveforms of Figures 5 and 6 are at a point where gamma equals 0.5, correction for gamma must be made to determine the actual electrical contrast ratio, C_e. The values for C_e then are 20% and 86% for the unenhanced and enhanced systems, respectively, and the operating value of contrast enhancement gain, G_c, for the conditions of Figure 5 is 86/20 or 4.3. Using Equation 3 where $C_o = C_R e^{(-\sigma_V R)}$, $C_o = 0.2e^{-(0.13 \times 9)} = 64\%$. Examination of the enhanced video shows that the shaded side of the ship was toward the camera and the background was brightened by specular reflection of the sun. Under these conditions 64% is a reasonable value for C_o. The range *ratio* that would result in displayed video from the contrast-enhanced system having a target contrast equal to that of the unenhanced system can be calculated.

Since the contrast enhancement gain has a maximum value of 7, this value will be used for G_c. Then for C_e = 20%,

$$R_2/R_1 = [\ell n G_c / \ell n (C_o/C_e)] + 1 = \left[\frac{\ell n 7}{\ell n \left(\frac{0.64}{0.20}\right)}\right] + 1 = 2.67$$

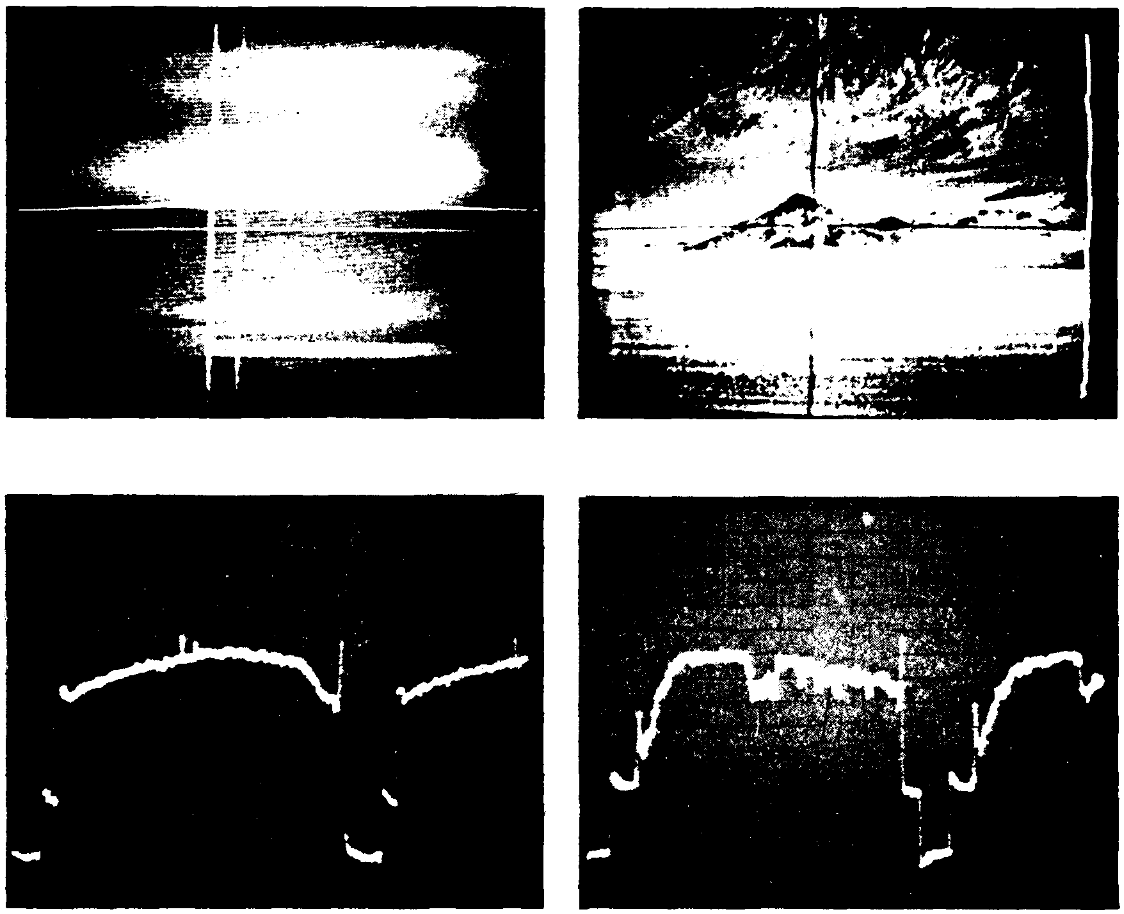
The standoff range for the ship target could then, under these conditions, be increased by a factor of 2.67 or from 9 km (approximately 30,000 ft) to 24 km (approximately 79,000 ft).



Standard Walleye

Contrast—Enhanced Condor

FIGURE 5. Ship Target Through Moisture Haze.



Standard Walleye

Contrast—Enhanced Condor

FIGURE 6. Mountain Target Through Smoke Haze.

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